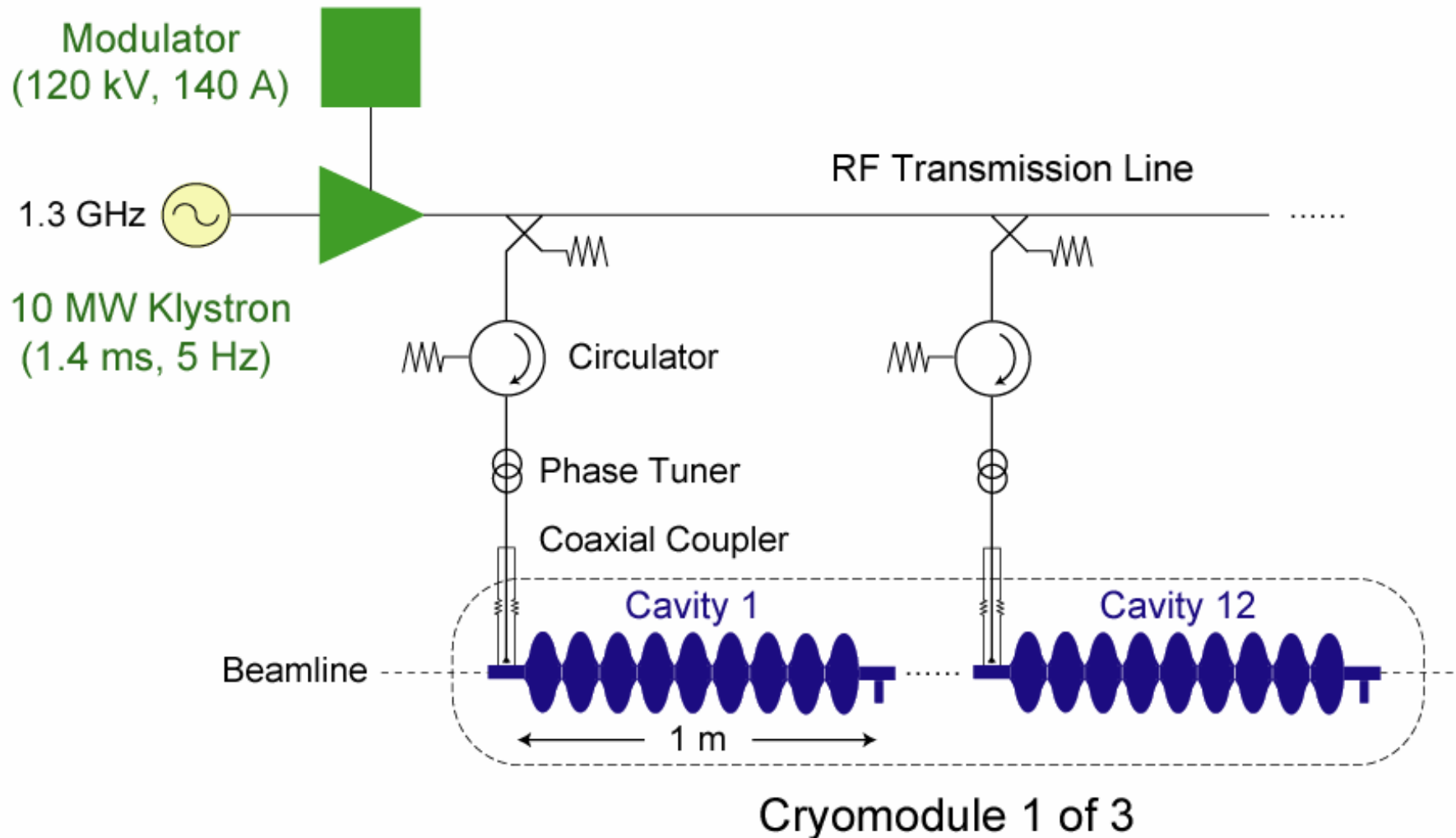


ILC R&D at SLAC & Opportunities for Industry



ILC Industrial Forum @ FNAL
Chris Adolphsen
SLAC

International Linear Collider (ILC) RF Unit (1 of 600, TESLA TDR Layout)

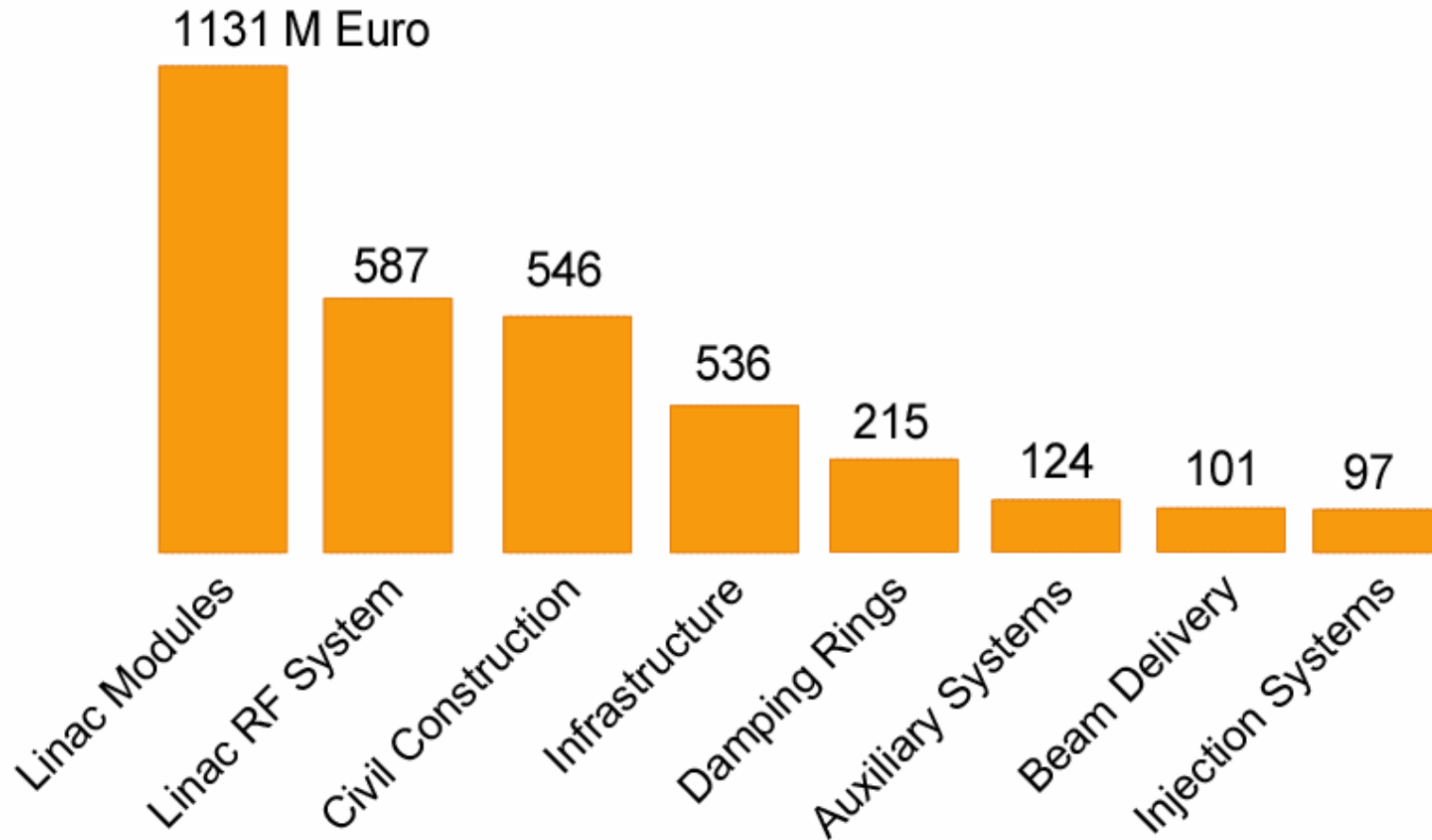


ILC RF Sources Overview

- Industry built modulators and 5 MW and 10 MW klystrons are available although baseline 10 MW tube not fully proven. Need about 600 rf units for the ILC.
- The SC linac for the X-ray FEL (XFEL) project at DESY requires 35 rf units but run at lower power:
- Initial SLAC program will focus on:
 - Establishing a 1.3 GHz test stand to gain experience with L-band technology and to test NC structures and cavity power couplers.
 - Developing alternatives to the baseline modulator and klystron to reduce cost and improve efficiency and reliability.

TESLA TDR Cost Estimates

(RF Sources ~ 1/3 Linac Cost)



Modulators for ILC

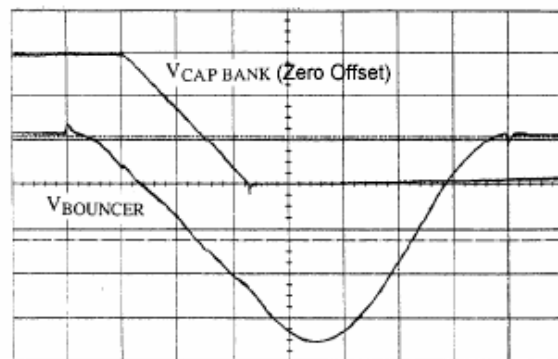
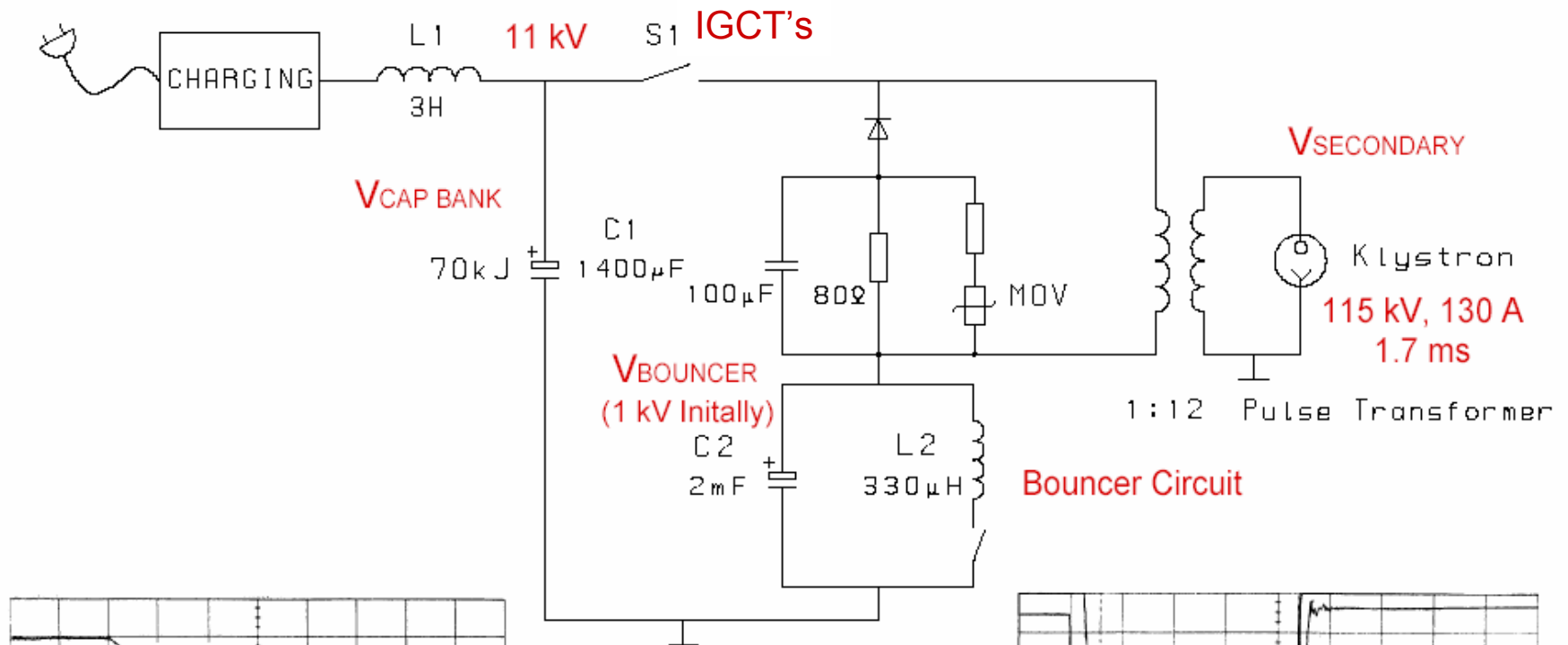
Requirements

RF Pulse Length	1.37 ms
Modulator Rise/Fall Time	0.2 ms max
Modulator Pulse Length	1.7 ms max
Klystron Gun Voltage	120 kV max
Klystron Gun Current @120kV	140 A max
Pulse Flatness	+/- 0.5%
Total Energy per Pulse	25 kJ
Repetition Rate	5 Hz
Modulator Efficiency	85%
AC Power per RF Station	120 kW
Number of Modulators	~ 600

- ILC baseline choice is the FNAL/DESY/PPT 'Pulse Transformer' modulator.
- SLAC is evaluating alternative designs (SNS HVCM, DTI Series Switch and Marx Generator).

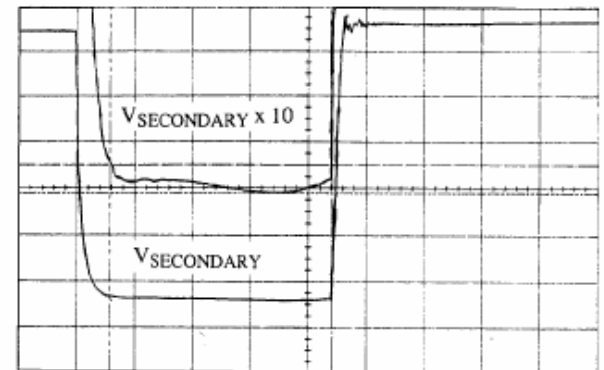
ILC Baseline Modulator

FNAL Design in Which a Bouncer Circuit Offsets the Voltage Droop (19%) During Discharge of a Capacitor Bank



500 V/div

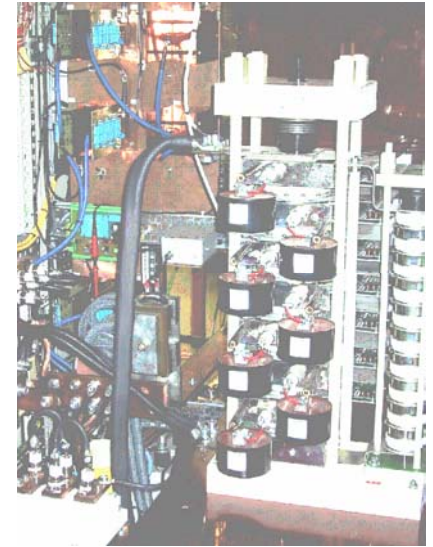
2 kV/div (top)
20 kV/div (bottom)



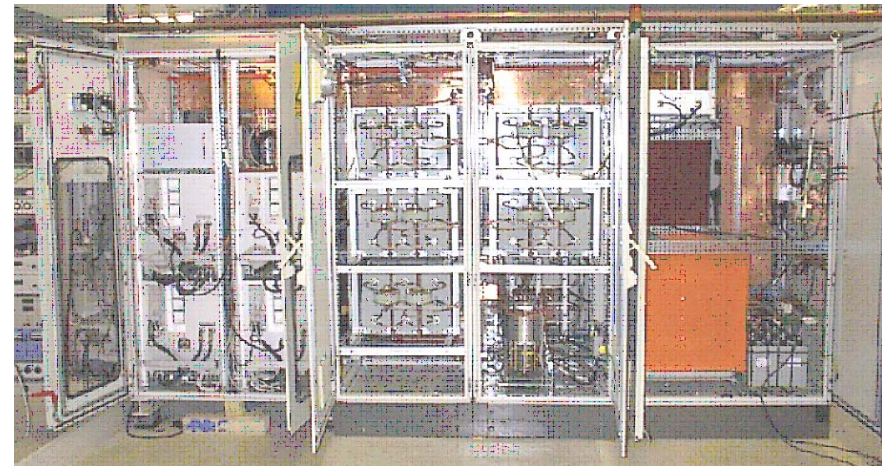
Pulse Transformer Modulator Status

- 10 units have been built, 3 by FNAL and 7 by industry (PPT with components from ABB, FUG, Poynting).
- 8 modulators are in operation.
- 10 years operation experience.
- Working towards a more cost efficient and compact design.
- **FNAL will build two more, one each for ILC and Proton Driver programs – SLAC will provide switching circuits.**

IGCT Stack



HVPS and Pulse Forming Unit



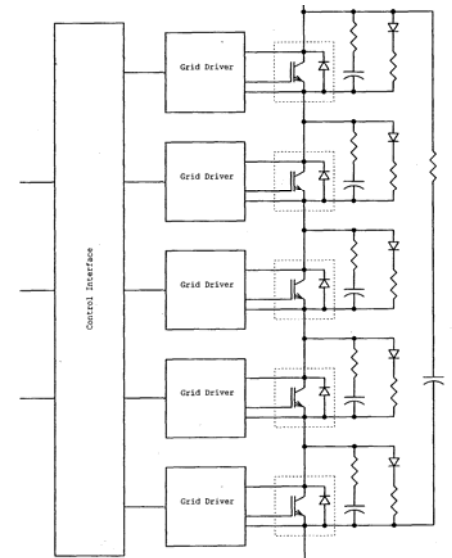
New Switch Design Provided by SLAC



Two IGBT's stacks
similar to that above

- Light triggered
- Water cooled
- Snubbers not shown

- 10 kV Nominal operation
- >2.5 Voltage safety factor
- 1700 Amp pulsed current
- >2.4 Current safety factor
- 5.1 msec pulse @ 3 PPS
- IGBT's cycling life time $>10^9$ Pulses @ 99% confidence
- Redundant pulse input control
- Detection and opening of switch in case of a single fault
- Snubbers designed to prevent cascade failures during turn off

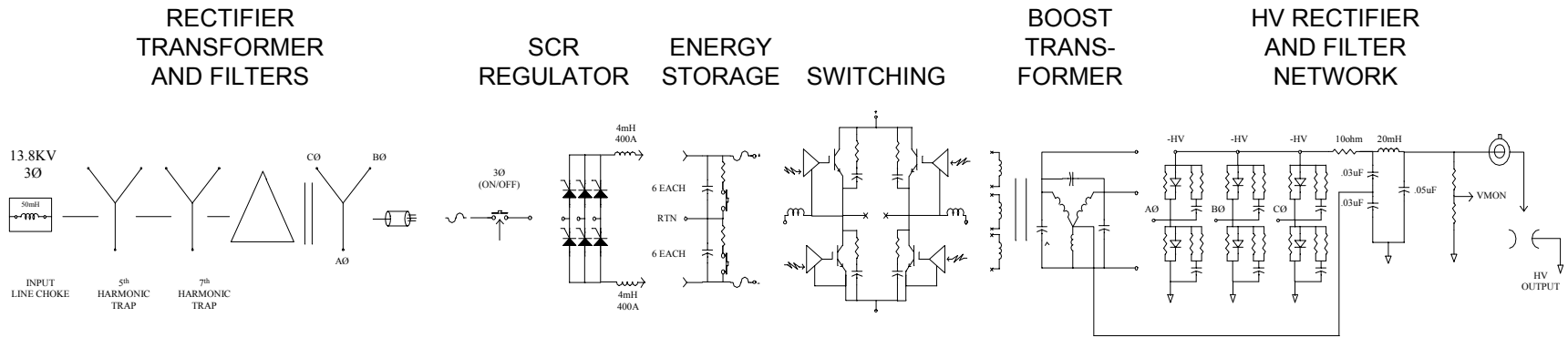


Switch Schematic

- Redundant drive
- Independent snubbers

Alternative ILC Modulators

SNS High Voltage Converter Modulator (Recently Acquired a Production Unit from SNS)



RECTIFIER
TRANSFORMER
AND FILTERS



SCR
REGULATOR



HVCM



EQUIPMENT
CONTROL RACK

Series Switch Modulator (Diversified Technologies, Inc.)

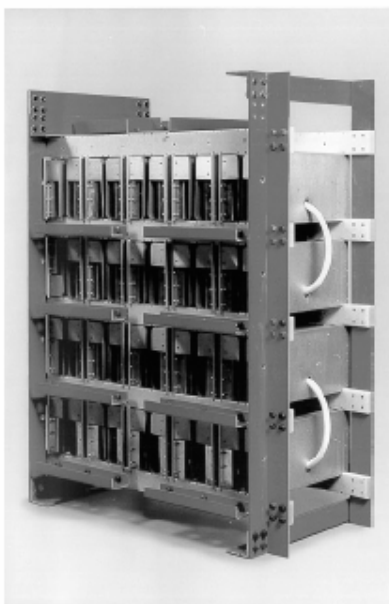
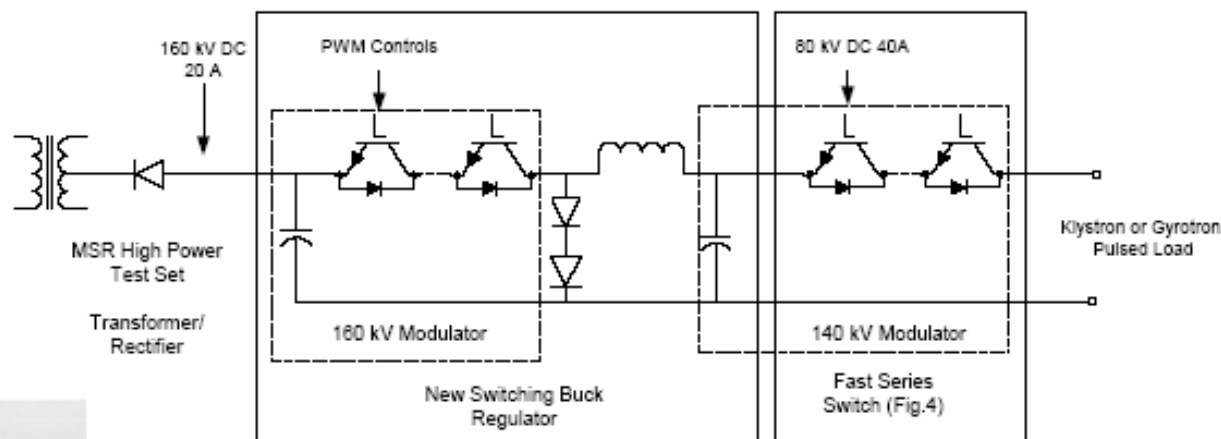


Figure 2. 140kV, 500A solid-state switch

- IGBT Series Switch
- 140kV, 500A switch shown at left in use at CPI
- As a Phase II SBIR, DTI will produce a 120 kV, 130 A version to be delivered to SLAC for the Klystron Program

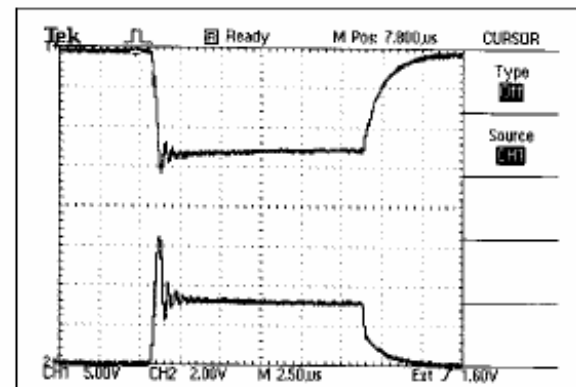
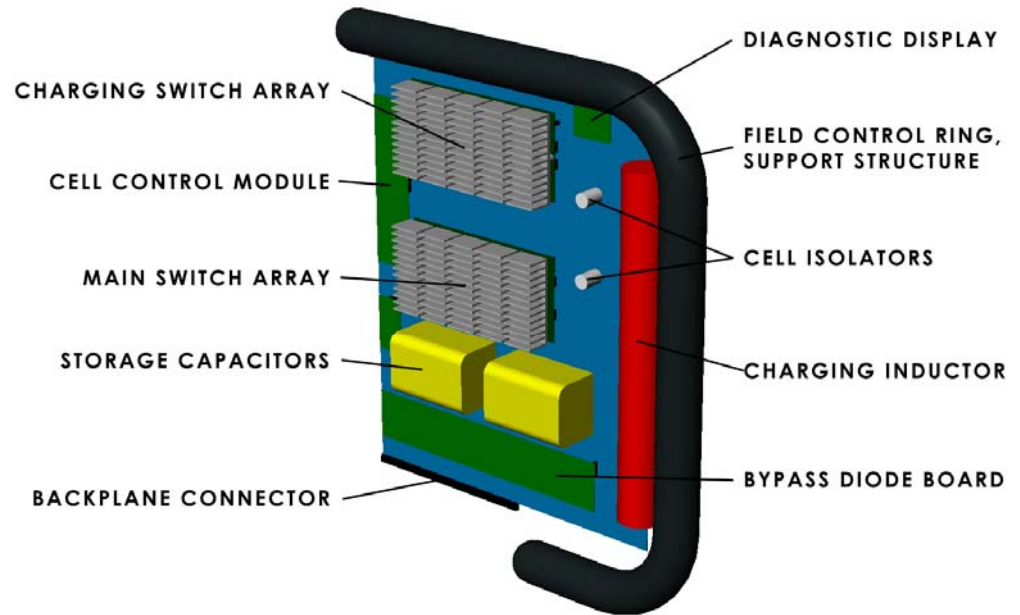
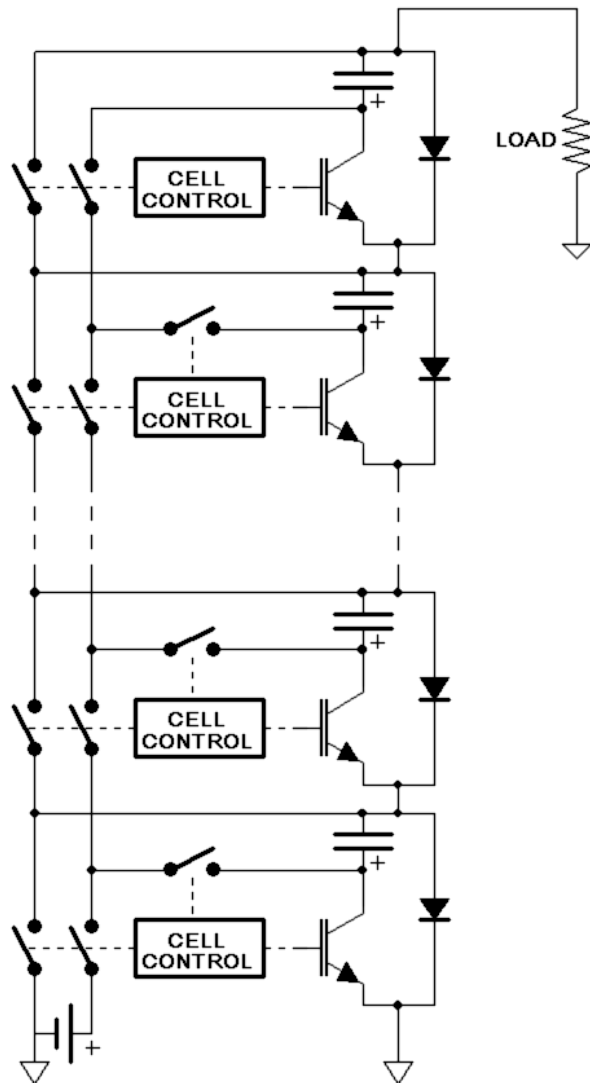


Figure 3: Test pulse (140 kV, 160 A, 13 μsec) of solid-state modulator. Upper trace is voltage at 63 kV/division. Lower trace is current at 100 A/division

SLAC Marx Generator Modulator



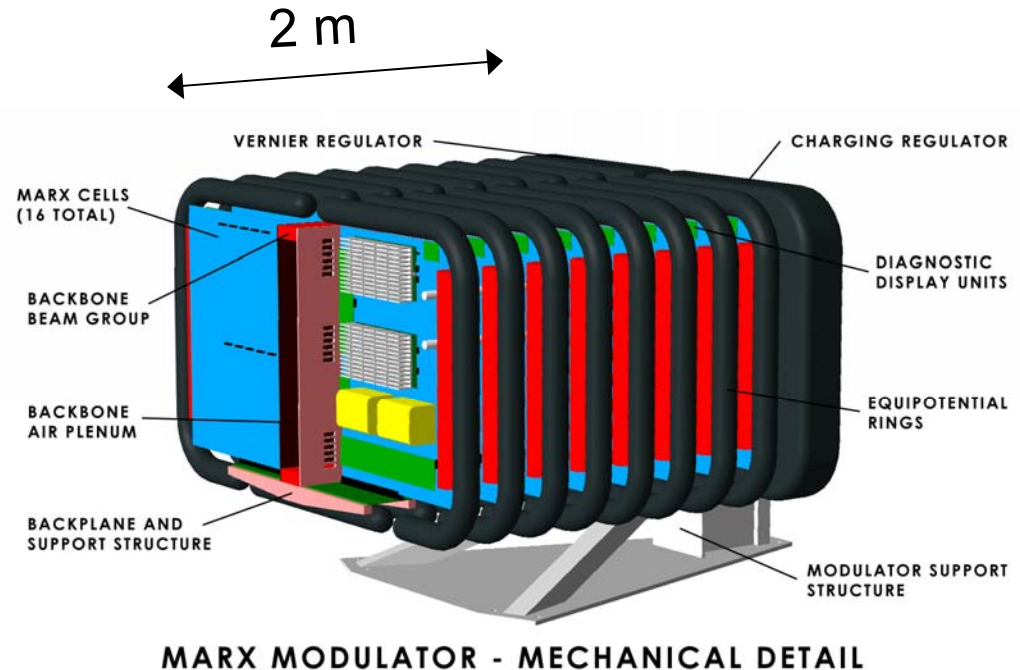
MARX CELL COMPONENT LAYOUT

12 kV Marx Cell (1 of 16)

- IGBT switched
- No magnetic core
- Air cooled (no oil)
- Building prototype (8/2006)

Prototype Development Approach

- Start with the highest technical risk items – 12kV switch, energy storage capacitors.
- Assemble, test, debug a complete cell.
- Work towards developing a 'short stack.'
- Explore stack-level fault scenarios.
- Design, test the active regulation control loop.
- Develop complete modulator, control system, RF station. Integrate with L-Band klystron.



Klystrons

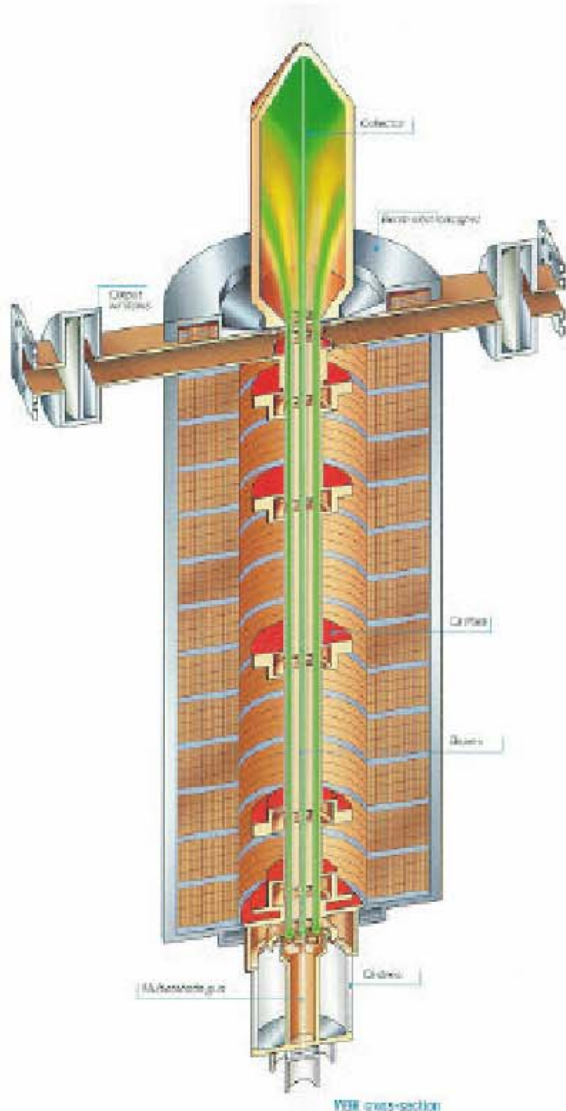
- The 1.3 GHz 'workhorse' tube for operation and testing at FNAL and DESY is the Thales 2104C single beam klystron. It produces 5 MW, 2 ms pulses at up to 10 Hz.
- Its 46% efficiency is low compared to that achievable ($\sim 70\%$) at lower perveance – it is not an ILC candidate.

In service over
30 years

- High peak power in long pulses: 2 ms
- High average power: up to 250 kW
- Electromagnetic beam confinement by solenoid
- High efficiency and gain
- Proven reliability by design, long life



ILC Klystron Development



GOAL

Reduce HV Requirements
and Improve Efficiency
(Lower Space Charge)
with a
Multiple Beam Klystron

Use Seven 19 A, 110 kV
Beams to Produce 10 MW
with a 70% Efficiency

Thales TH1801 MultiBeam Klystron

Spec's:

10 MW, 10 Hz, 1.5 ms
with 4 kW Solenoid Power

First Tube Achieved 65%
Efficiency at 1.5 ms, 5 Hz
and Is Used in TTF

2.5 m



Photo of TH1801 Tube
(top) and Cathode (bottom)

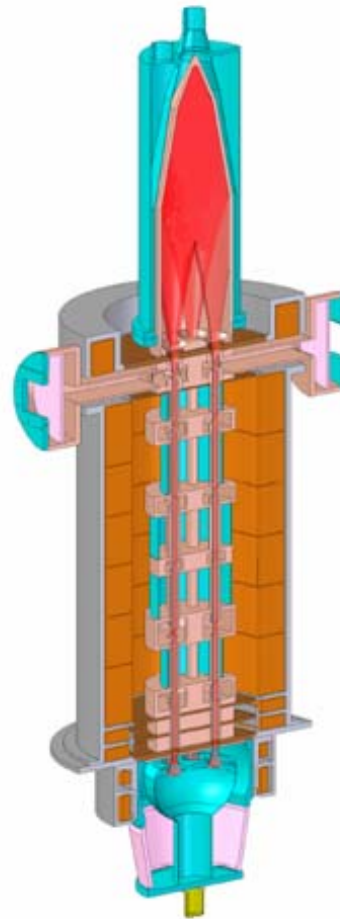


Other 10 MW
Multi-Beam
Klystrons
Being Developed

TOSHIBA E3736 (Collaboration with KEK)

Features

- 6 beams
- Ring shaped cavities
- Cathode loading $< 2.1 \text{ A/cm}^2$
- Expect ~ 100 khour cathode lifetime compared to ~ 40 khours for the Thales tube





VKL-8301

Features

- Six cathodes with six heater feed-throughs
 - can turn off individual cathodes
- Six cavities in each beam-line
 - three fundamental-mode with external tuners
 - one second-harmonic
 - two common HOM (input & output)
- Six isolated collectors
 - can measure intercepted current in each beam-line
 - one main collector water manifold
- Low cathode loading
 - Expect ~ 100 khour cathode lifetime



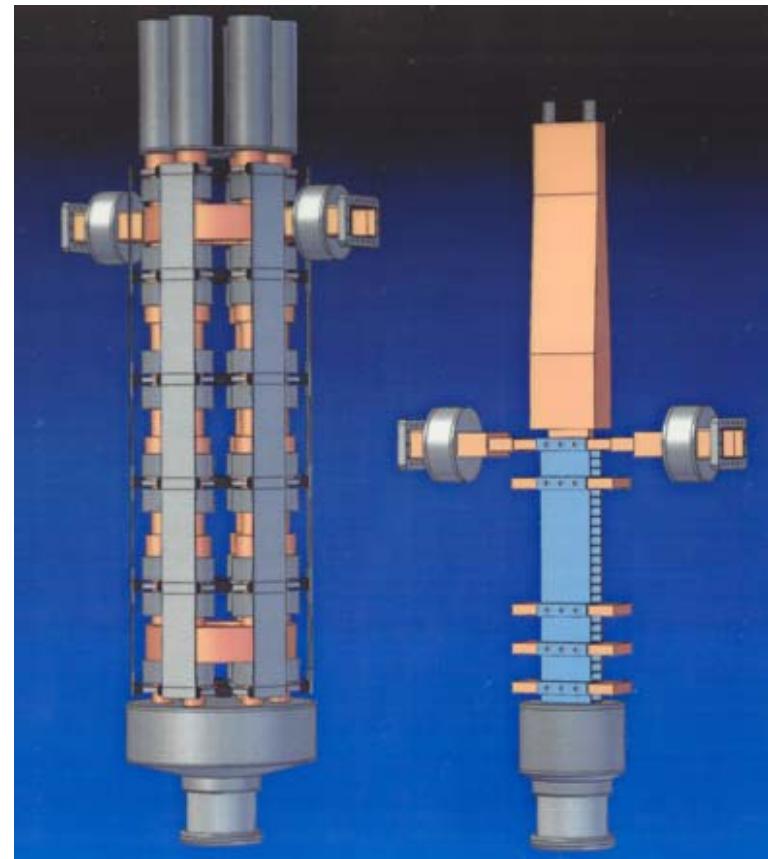
Klystron Status / Program

- DESY 10 MW Klystron Program
 - Three Thales tubes built, five more ordered – two have meet full specs but only run a few hundred hours.
 - One CPI tube built – achieved 10 MW at short pulse length, limited by CPI modulator - was accepted by DESY, may come to SLAC after testing at DESY.
 - One Toshiba tube built and under test – 10 MW, 1 ms achieved – longer pulses limited by modulator, which is being upgraded.
- SLAC Klystron Program
 - Developing a 10 MW L-band Sheet-Beam Klystron (currently no funding).
 - If multi-beam program falters, consider lower perveance, single beam, 5 MW tube, possibly with PPM focusing.
 - Buy commercial 5 MW tubes as needed for 1.3 GHz NC structure and coupler program.
 - Possibly collaborate with DESY and CPI on 10 MW tube.

SLAC Sheet-Beam Klystron

- Developing a 10 MW sheet beam klystron as an alternate to the multi-beam tubes to reduce cost
 - Uses flat beams instead of six beamlets to reduce space charge forces.
 - It is smaller with a planar geometry for easier construction.
 - No solenoid magnet (saves ~ 4 MW of power).
 - Would be plug compatible with baseline design and have similar efficiency.
 - W-band ‘proof-of-principle’ version in progress using external funding.

Multi-beam tube Sheet-beam tube



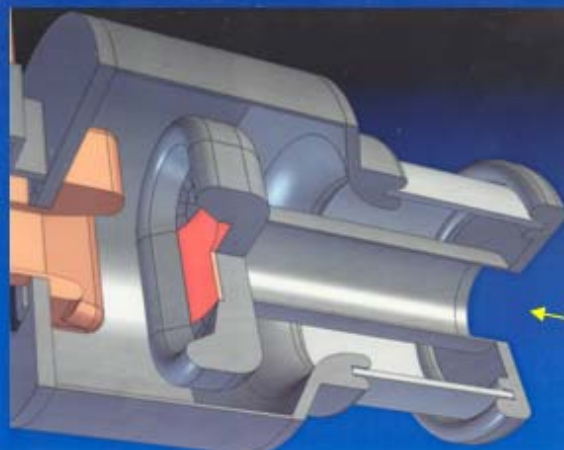
10 MW L-Band Sheet-Beam Klystron

Collector

Output
Cavity

Wiggler Type
Focusing Using
Permanent Magnets

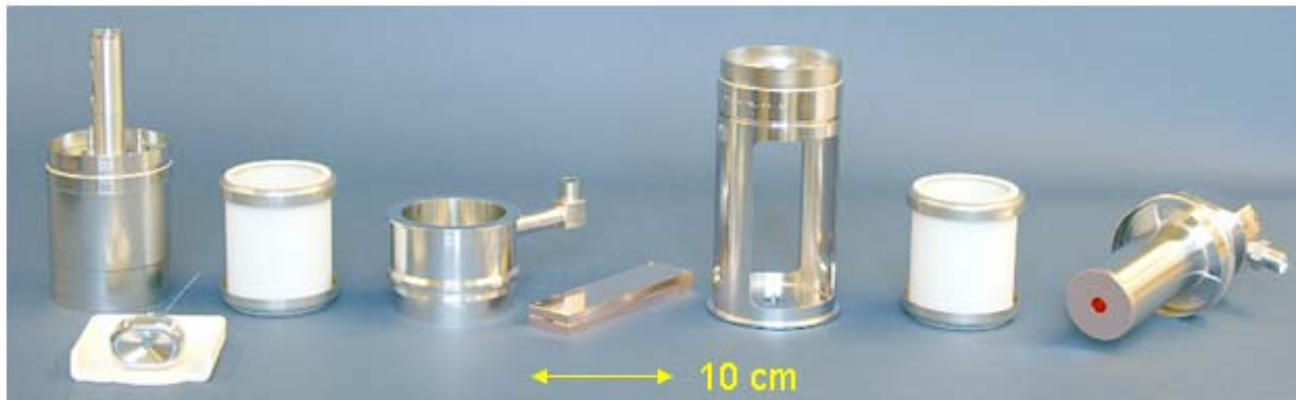
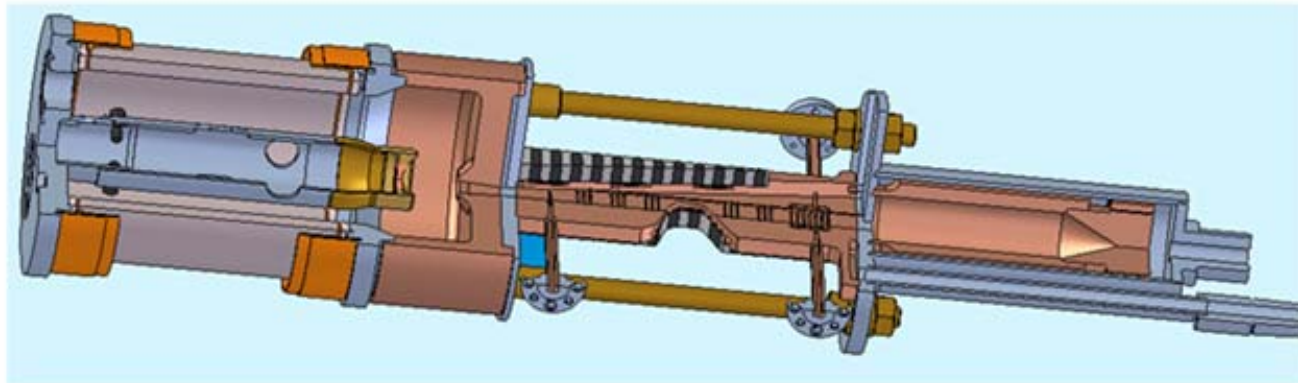
Gun



W-Band Sheet Beam Klystron Program

(Not ILC funded)

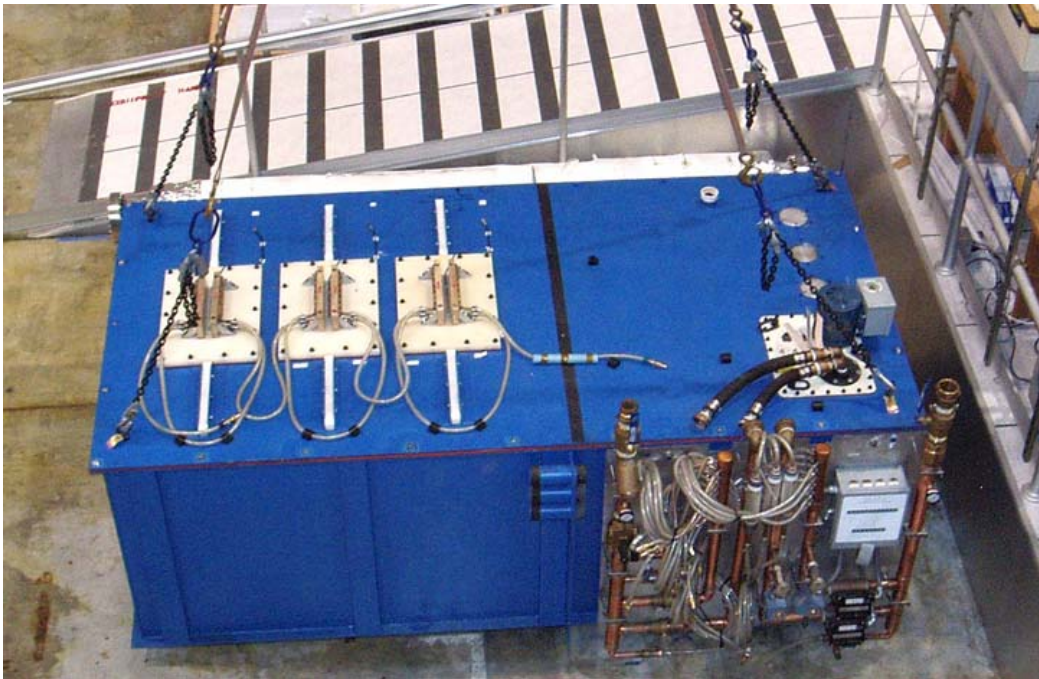
A 91 GHz, 100 kW peak power sheet-beam klystron (74 kV, 3.6 A beam) has been designed and is being fabricated (currently under test).



L-Band Test Facility at SLAC

- Recently acquired a 10 MW HVCM Modulator from SNS.
- Buying a 5 MW TH2104C tube from Thales (1 year delivery).
 - In meantime use a SDI-Legacy tube from Titan (TH2104U).
- All major LLRF and waveguide components on order.

SNS Modulator Being Assembled at NLCTA



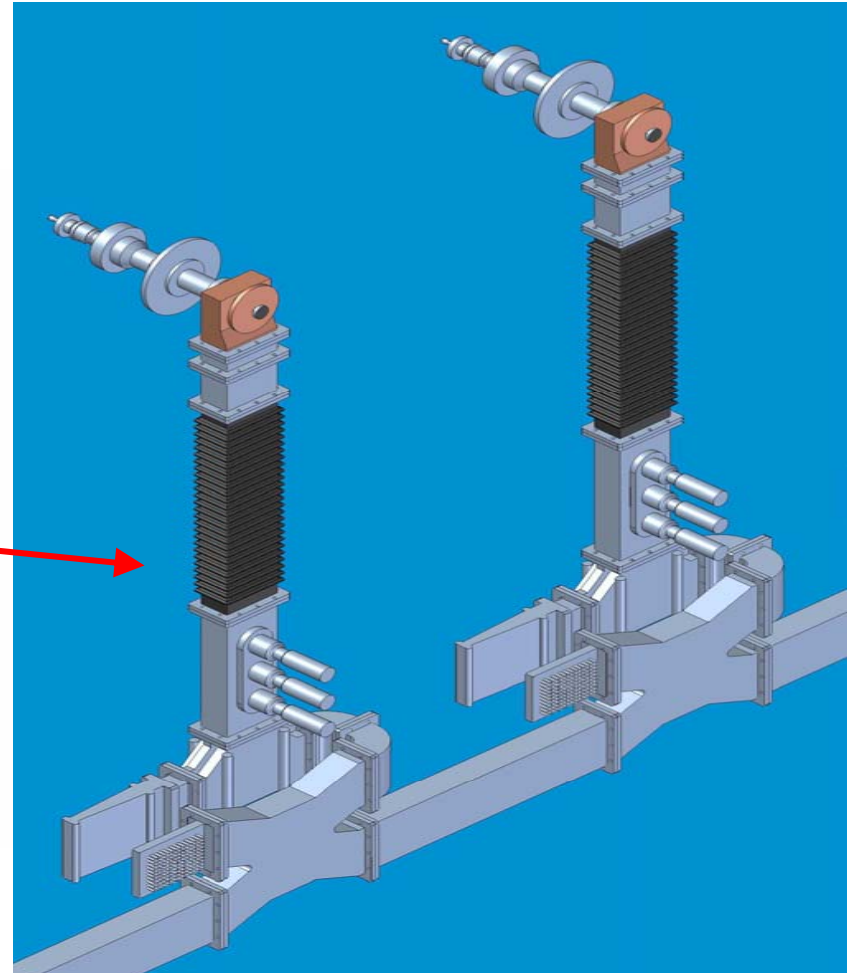
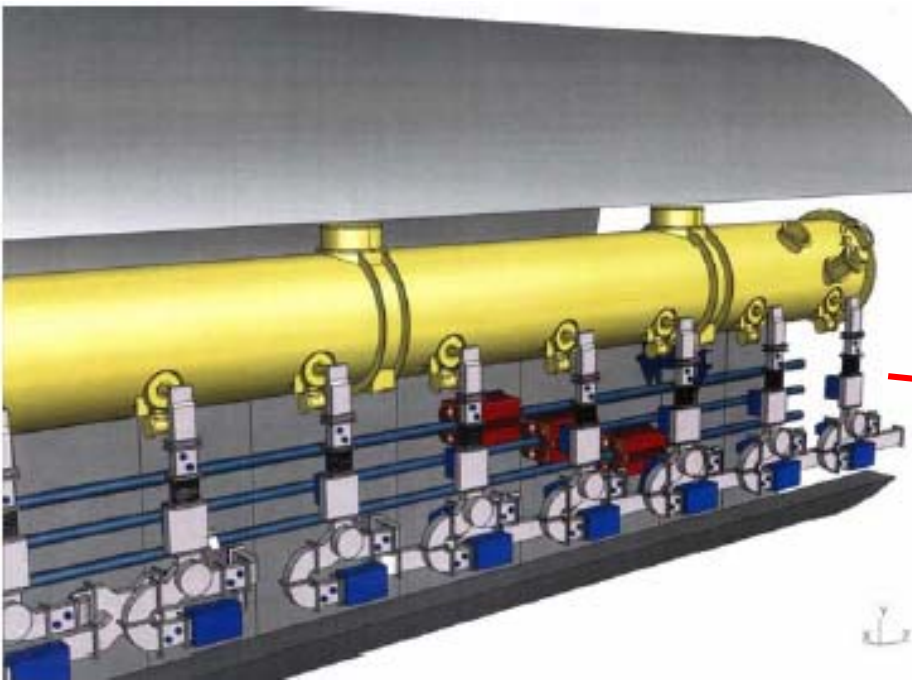
Thales 2104U Klystron

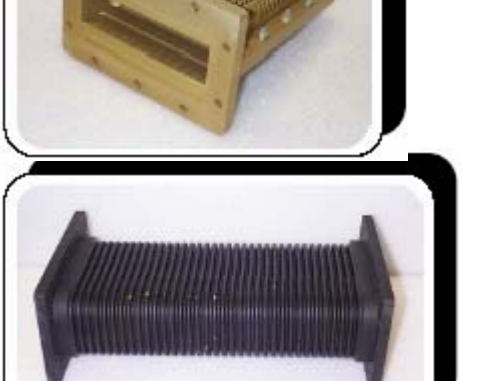
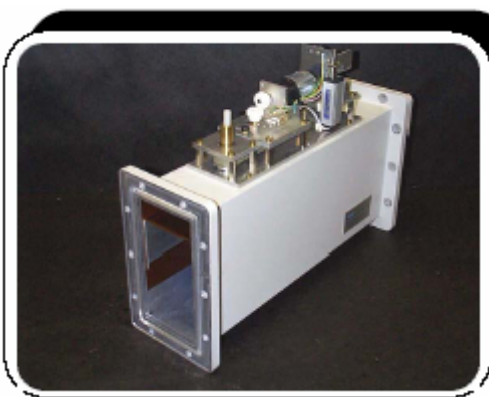


RF Distribution System

(Each Cavity Fed 350 kW, 1.5 msec Pulses at 5 Hz)

Two of ~ 20,000 Feeds



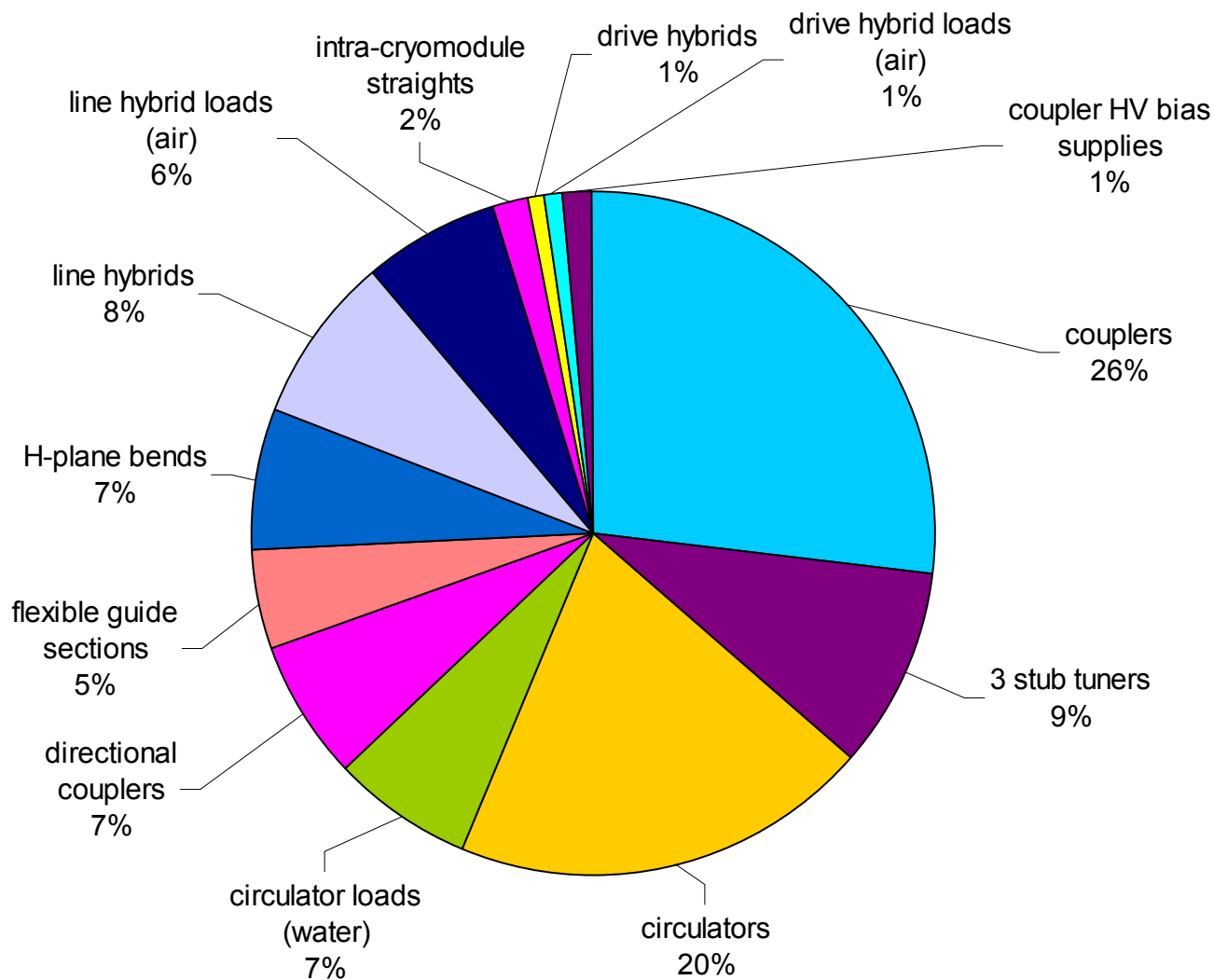


The RF distribution system is comprised of lots of complex parts, requiring time and effort to build

V.Katalev, A.Eislage, E.Seesselberg

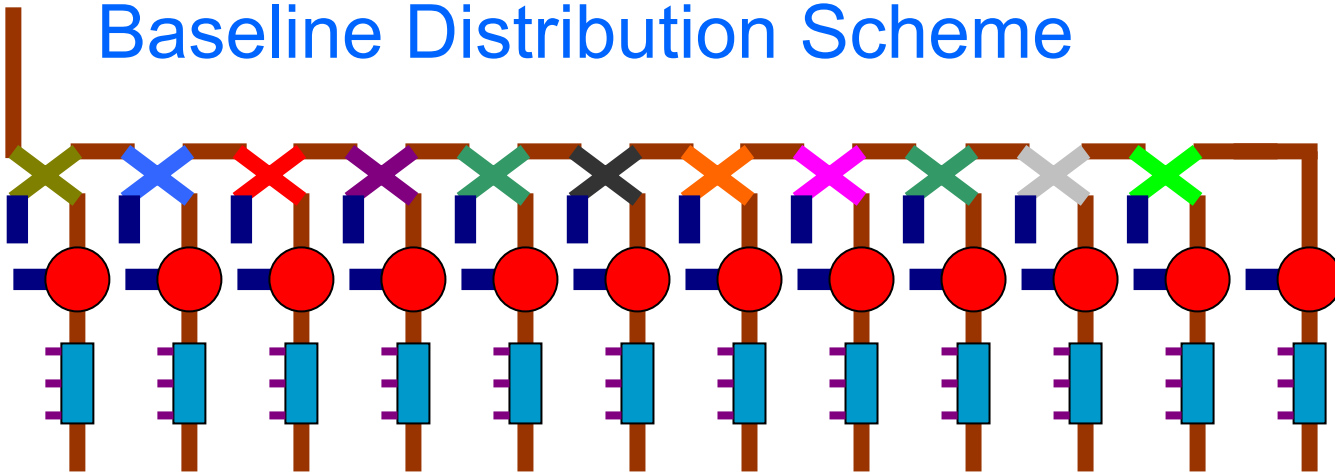
Brian Rusnak

An Assessment of Some Relative Costs - sans Klystron and Modulator



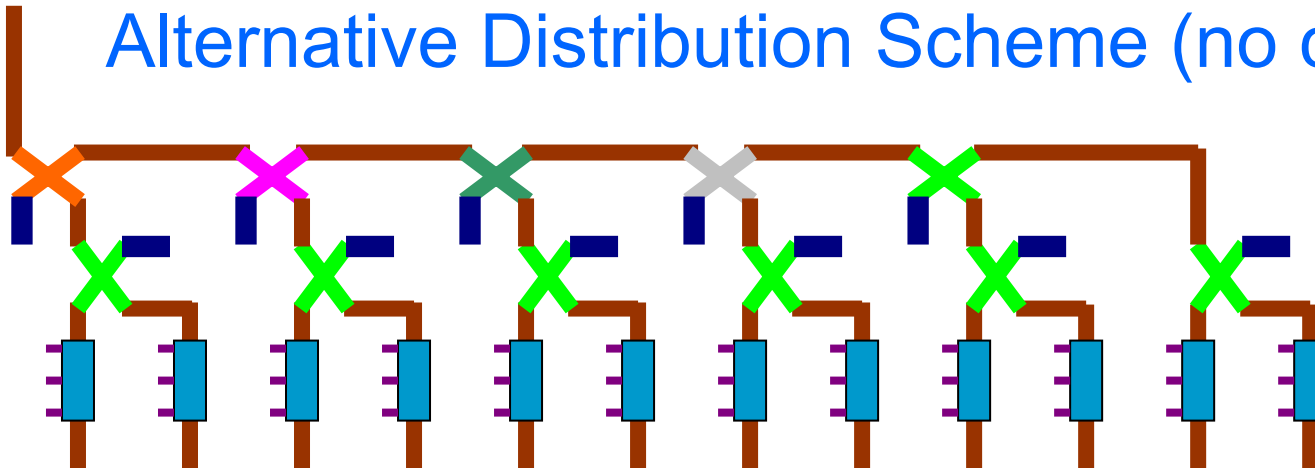
The assessment was done using a cost estimating exercise to determine what the relative costs of components were based on an independent evaluation of materials and effort to build components

Baseline Distribution Scheme



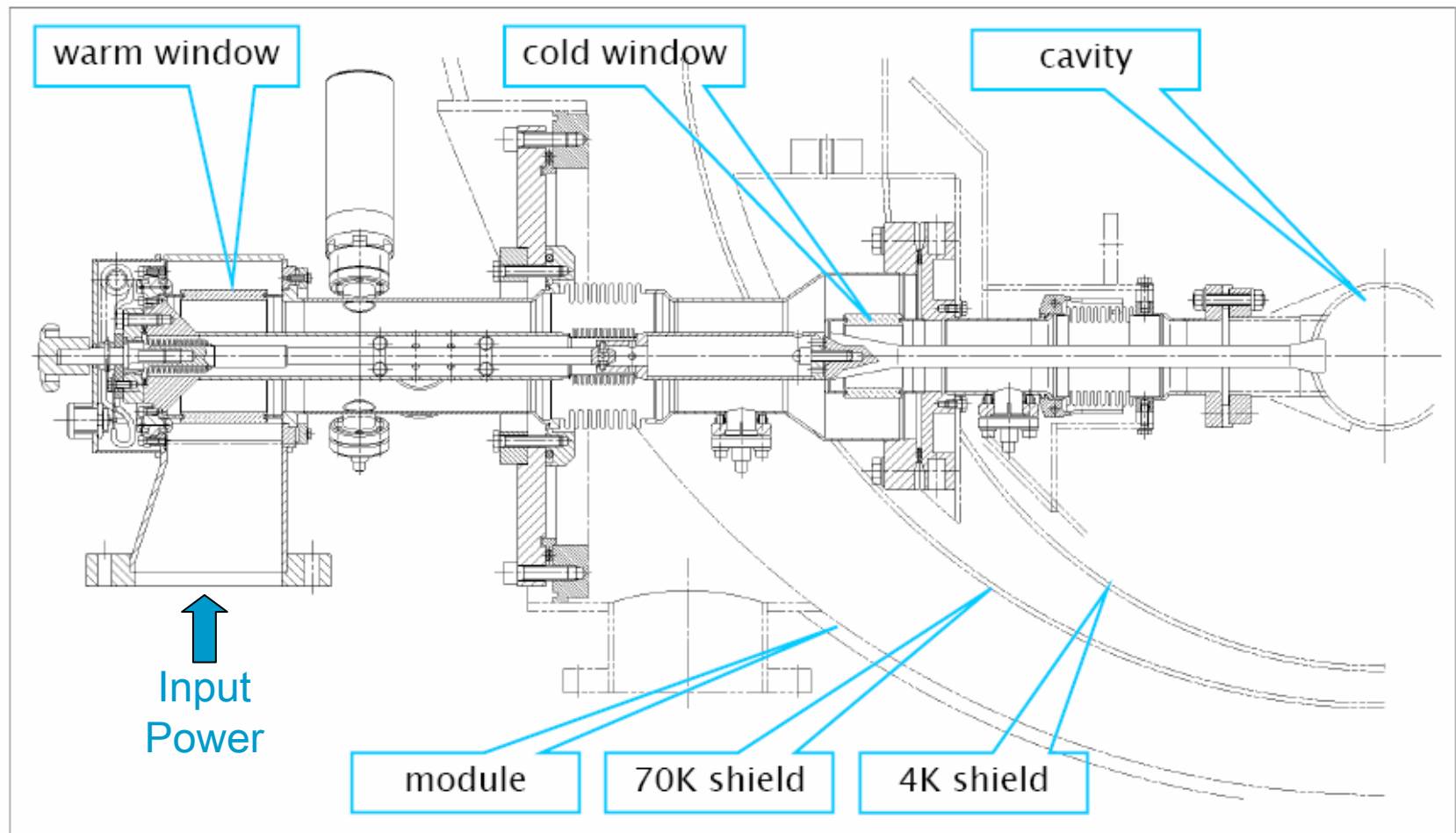
Similar to TDR and XFEL scheme.

Alternative Distribution Scheme (no circulator)



With two-level power division and proper phase lengths, expensive circulators can be eliminated. Reflections from pairs of cavities are directed to loads.

Coaxial Power Couplers for the Superconducting Cavities

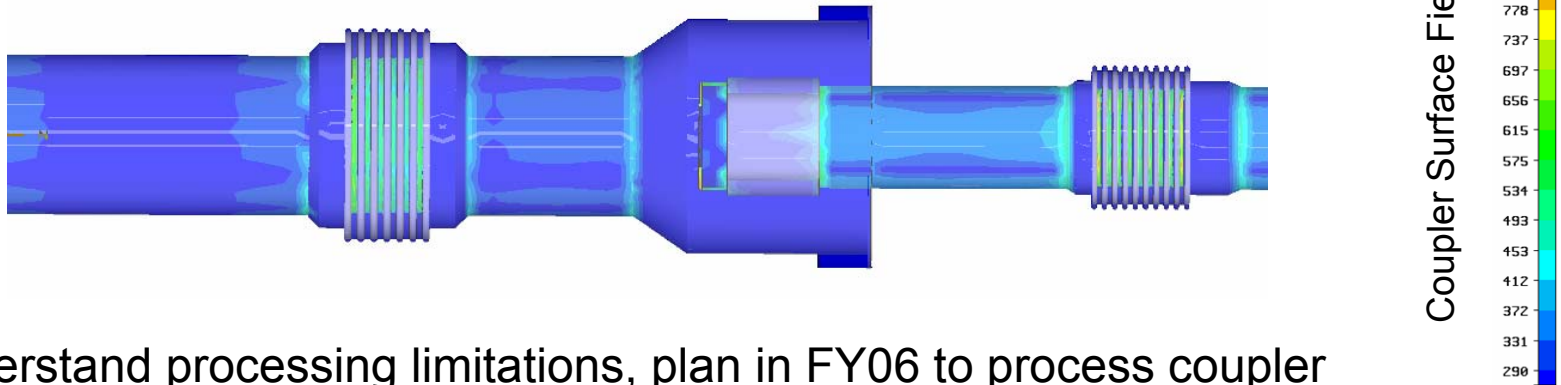


Coupler Overview

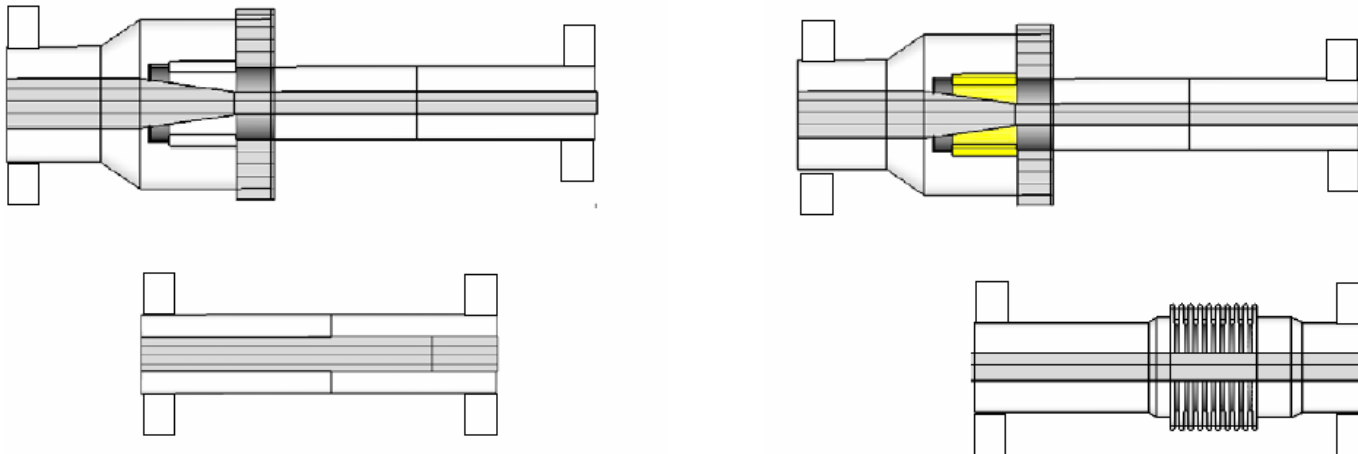
- Design challenging due to requirements of tunability, vacuum isolation and low heat loss.
- Extensive testing of TTF3 coupler at 20-25 MV/m but limited testing at 35 MV/m – performance acceptable but
 - RF processing is too slow (~ 100 hr, limited by outgassing; also require ~ 50 hr in-situ processing).
 - Cost too high (seeking 60% reduction from current cost).
- Main supplier is the US company CPI
 - Currently building 30 for XFEL cavity evaluation.
 - Will likely bid for at least 500 of the 1000 needed for the XFEL, whose cavities require $\sim \frac{1}{2}$ the input power of those in the ILC.
 - Would need 20,000 for ILC.

Coupler Processing Studies

One concern is that the surface field variations in the bellows and near the windows may lead to excessive multipacting.

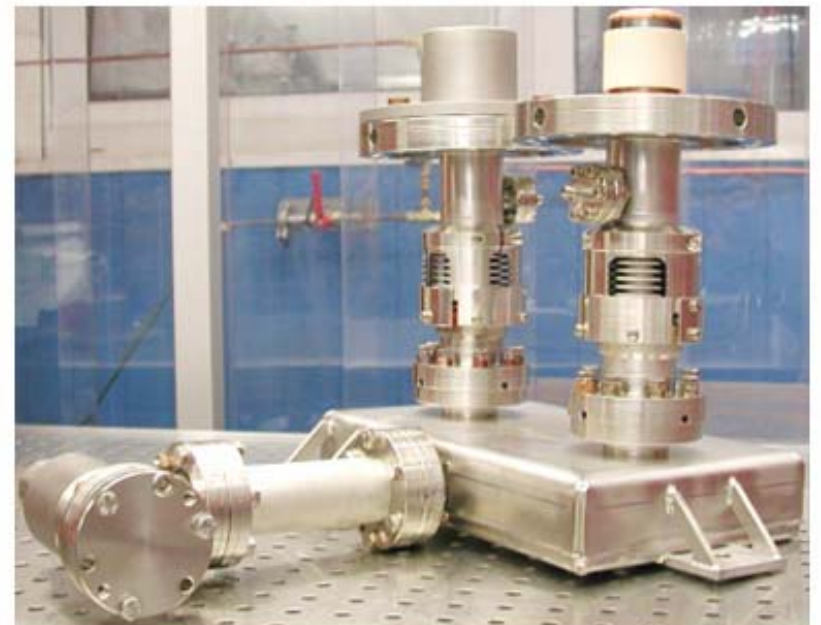
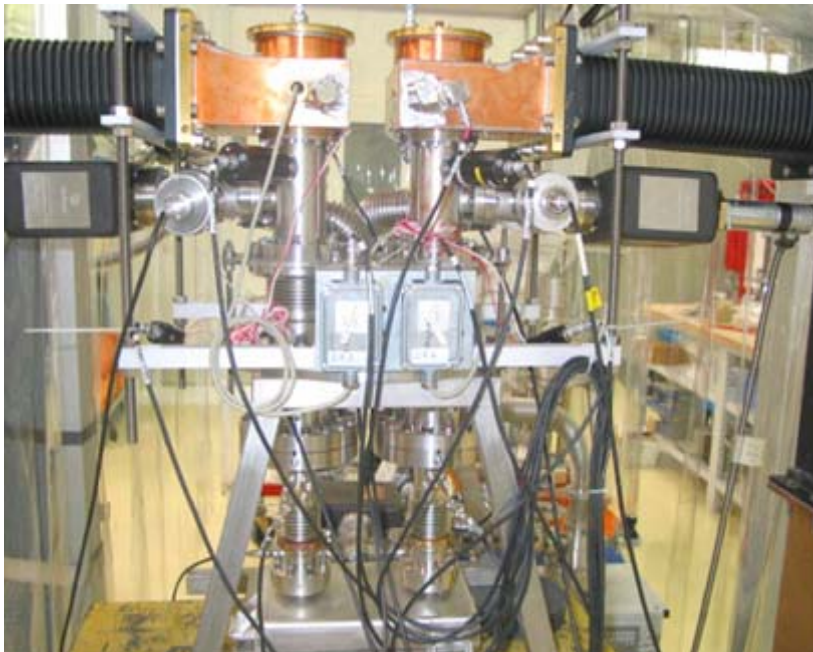


To understand processing limitations, plan in FY06 to process coupler components individually. In particular, determine if bellows or the windows are the source of the long processing time.

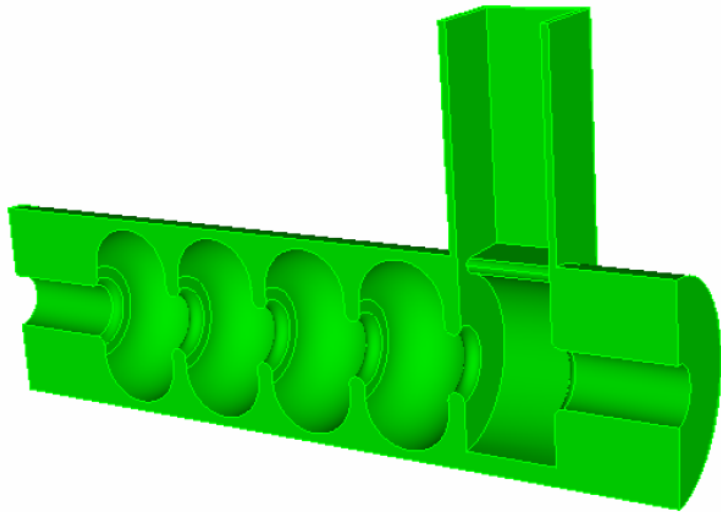


In FY06, May Setup a Coupler Test Stand to Process Couplers for SMTF Cavities

Instrumented Coupler Test
Stand at Orsay



Normal Conducting 1.3 GHz Structure for ILC Positron Capture Accelerator

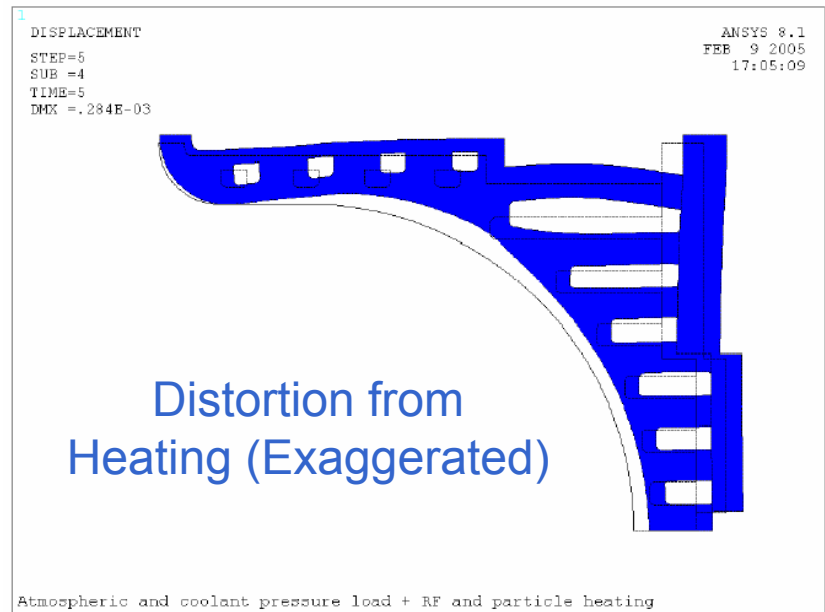
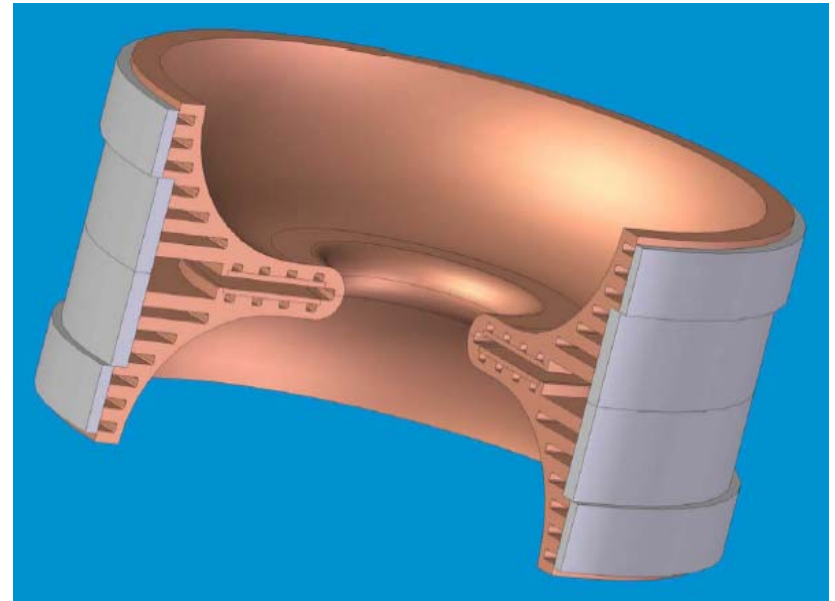


Pulse Temperature Rise < 20 deg C

Average Detuning = 69 kHz

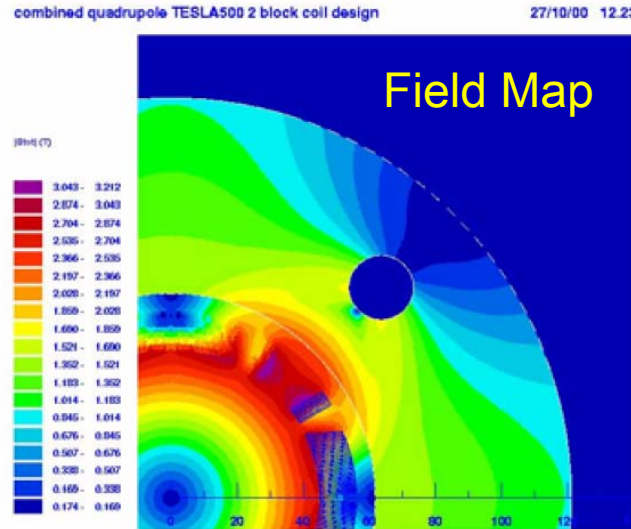
Pulse Detuning = 17 kHz

Will require a 5% power adjustment
during pulse for detuning compensation.

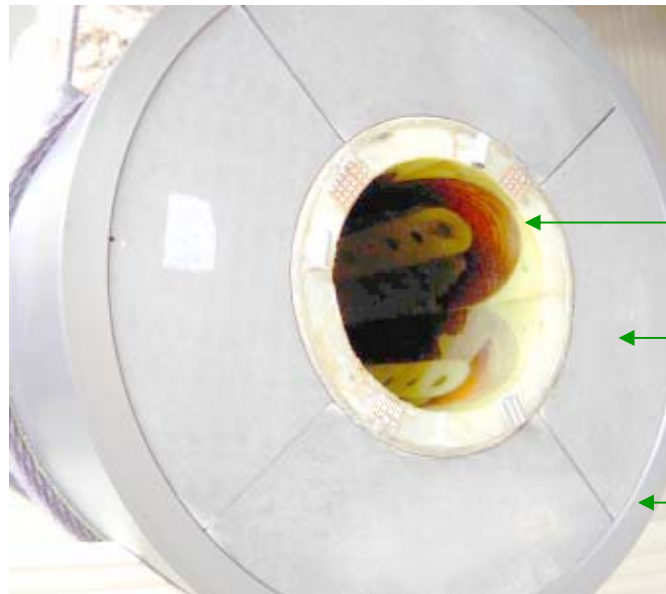
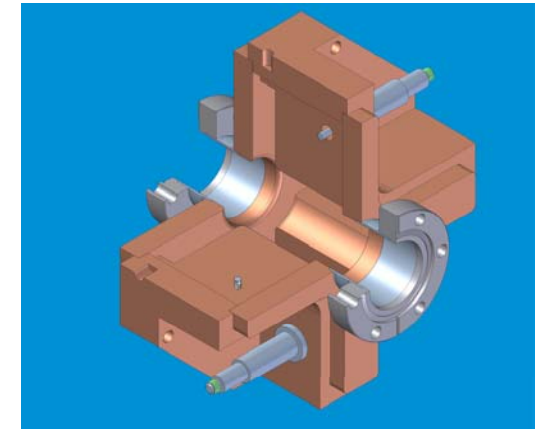


ILC Linac SC Quad/BPM Evaluation

Cos(2Φ) SC Quad (~ 0.7 m long)



S-Band BPM Design (36 mm ID, 126 mm OD)

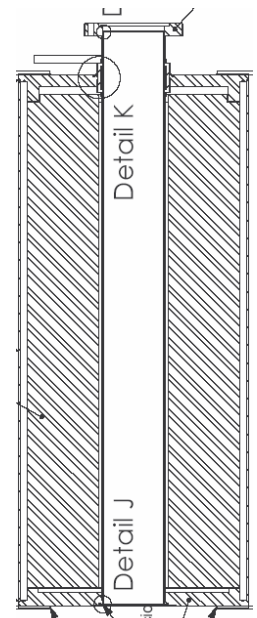


He Vessel →

SC Coils

Iron Yoke
Block

Al Cylinder



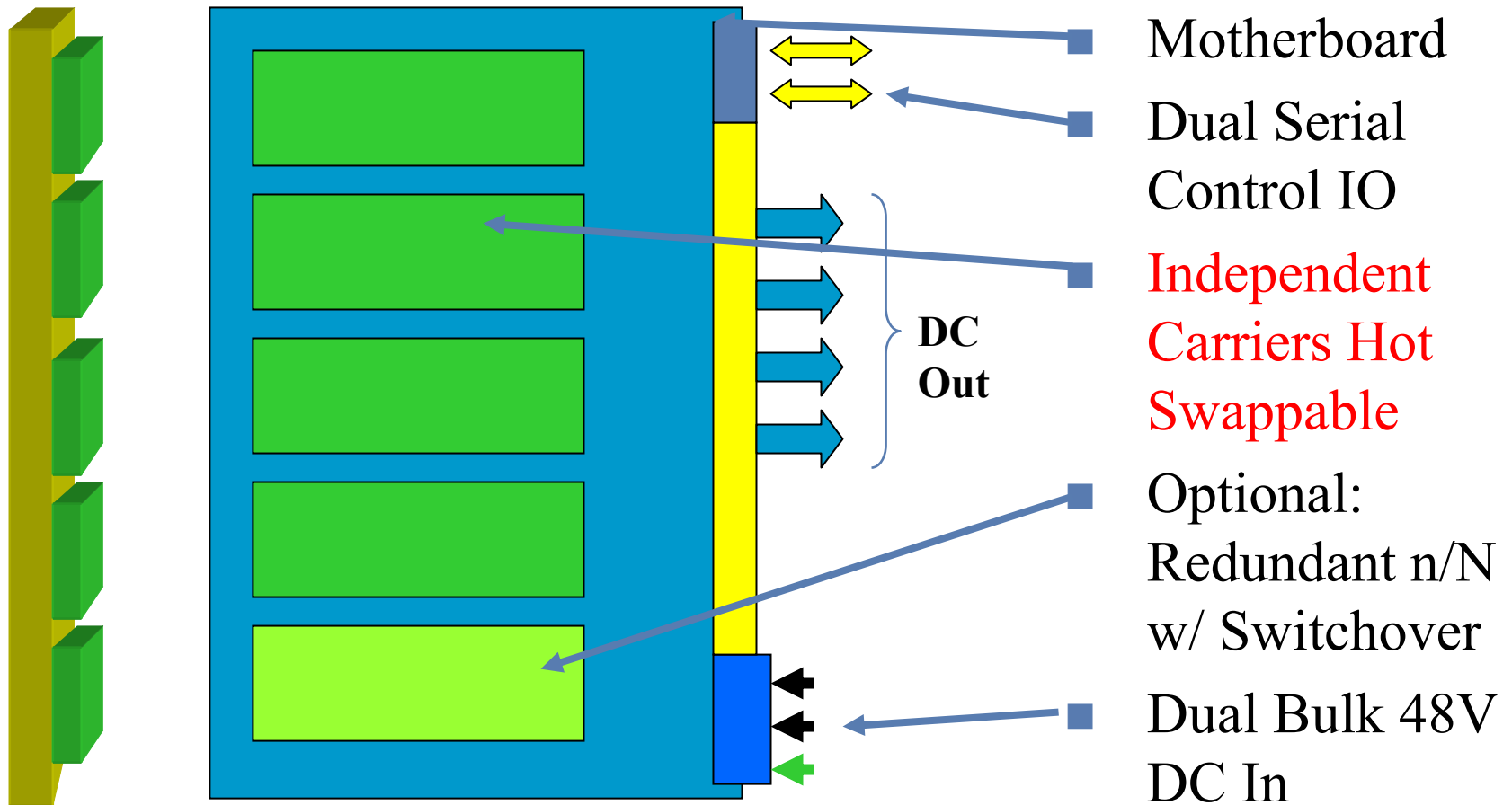
ILC Availability Challenge

- The ILC will be an order of magnitude more complex than any accelerator ever built.
- If it is built like present HEP accelerators, it will be down an order of magnitude more (essentially always down).
- For reasonable uptime, component availability must be much better than ever before. Must do R&D, plan, and budget for it up-front.

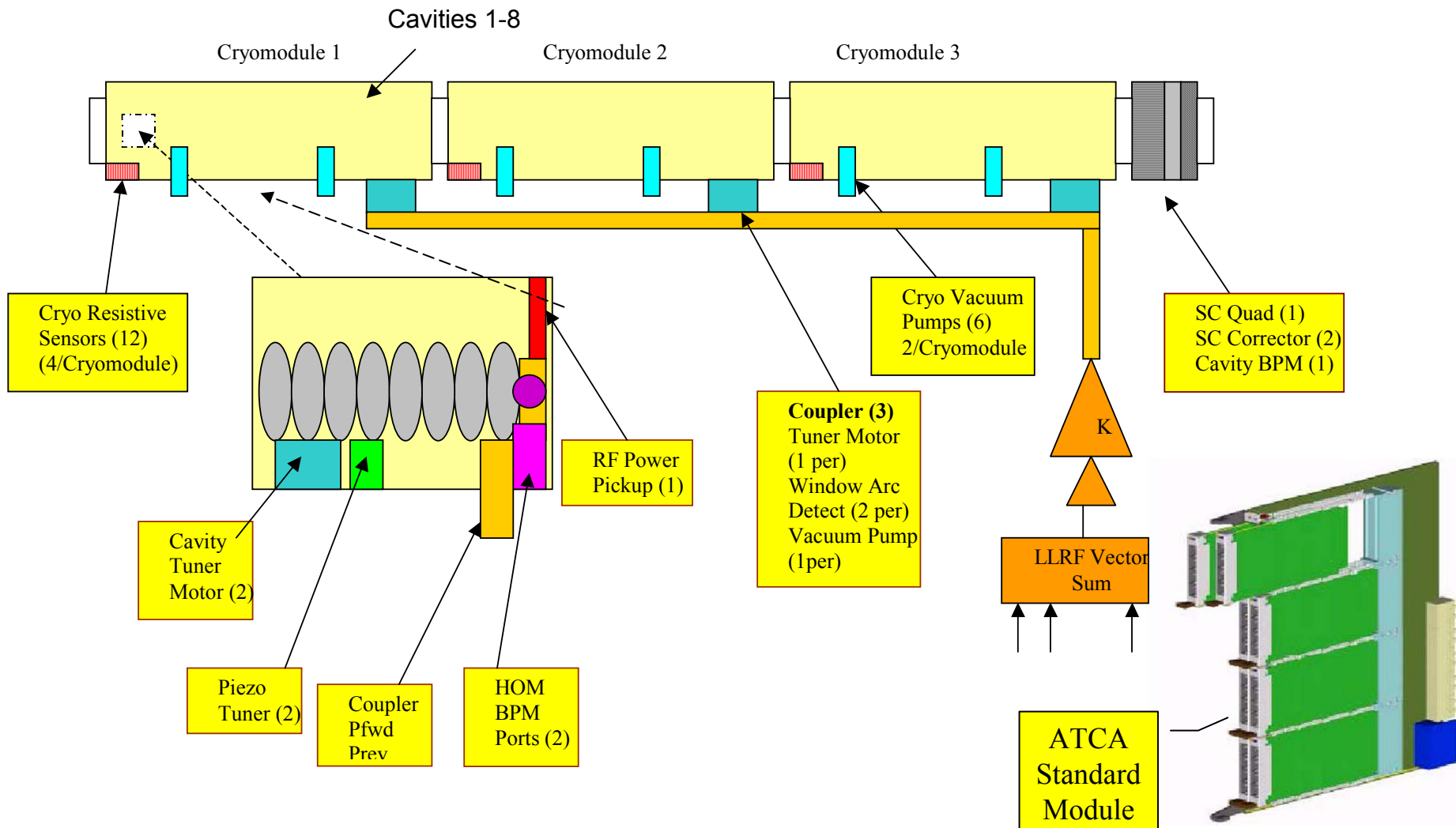
Lifetime Improvements

Device	Required MTBF Improvement Factor	MTBF from Present Experience (khours)
magnets - water cooled	20	1,000
power supply controllers	50	100
flow switches	10	250
water instrumentation near pump	10	30
power supplies	5	200
kicker pulser	5	100
coupler interlock sensors	5	1,000
collimators and beam stoppers	5	100
all electronics modules	10	100
AC breakers < 500 kW	10	360
vacuum valve controllers	5	190
regional MPS system	5	5
power supply - corrector	3	400
vacuum valves	3	1,000
water pumps	3	120
modulator		50
klystron - linac		40
coupler interlock electronics		1,000

High Availability Power Supply Module (Low Power)



ILC Linac Instrumentation (One of 600 RF Units)



Manufacturing

- All instrument packaging to be as far as possible in standard High Availability modules and hot-swappable sub-modules.
- Estimate ~ 1 Advanced Telecom Computing Architecture carrier card w/ sub-modules per meter of machine, ~25,000 total carriers, 100,000 mezzanine modules.
- Standard hardware and PC board techniques.
- Custom designs for high performance, reliability, minimum cost.